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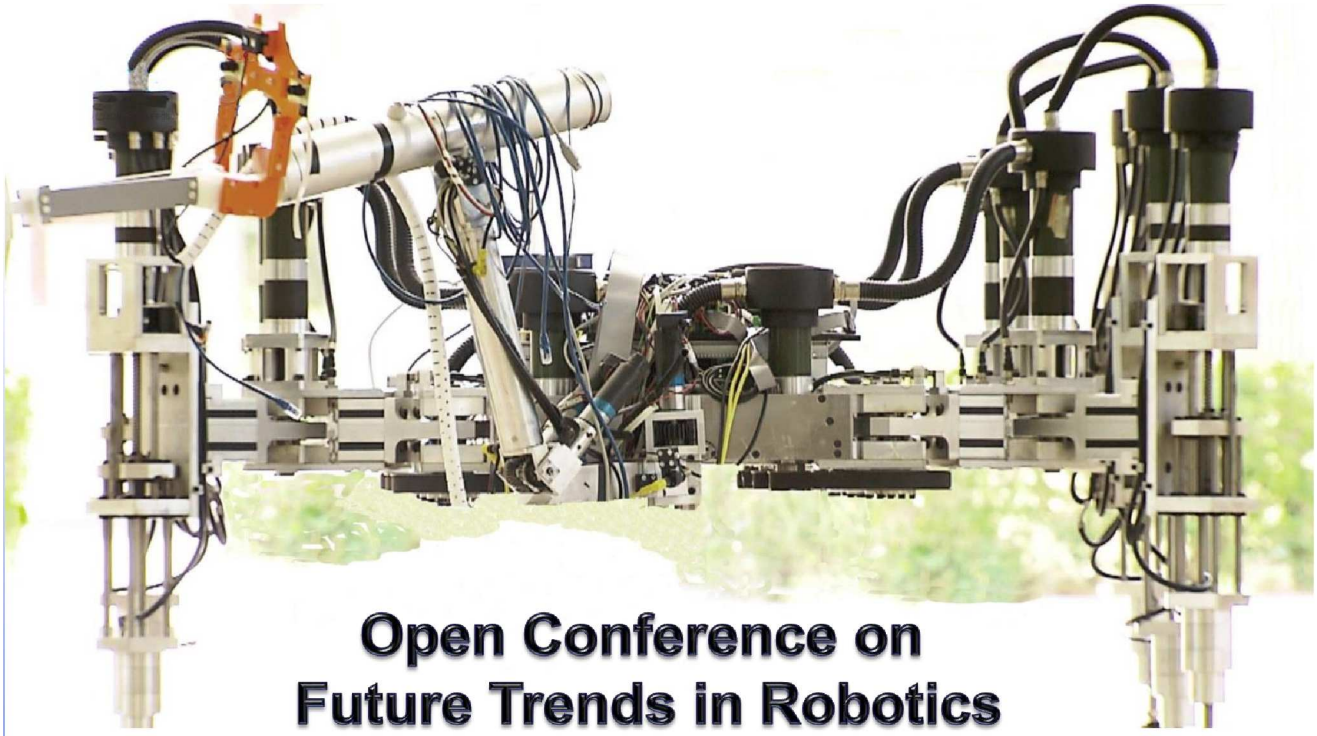

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CHAPTER 34

DETECTING, LOCALIZING AND FOLLOWING DYNAMIC OBJECTS WITH A MINI-UAV

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This paper presents an approach for the detection, localization and following of dynamic terrestrial objects using a mini-UAV. The development is intended to be used for surveillance of large infrastructures. The detection algorithm is based on finding several pre-defined characteristics of the target, such as color, shape and size. The process used to localize the target, once it is detected, is based on an inversion of the Pinhole camera model. The task of following the Summit XL was designed to keep the target inside the field of view of the camera, and it was implemented in the form of a PID controller. The system has been tested both in simulation and with real robots, showing promising results.

1 Introduction

Nowadays, the detection, localization and following of moving objects using Unmanned Aerial Vehicles (UAV) has grown up as an important task. This work is intended to be used for surveillance of large critical infrastructures, but its range of applications is very large.

The proposed system should be able to detect, localize and follow a moving target in a complex environment. This means that the system must be able to deal with unknown obstacles, as well as changes in the movement of the target.

Following moving objects might be seen as a trivial function for living beings. However, it is a complex task for autonomous robots, because it requires several sub-tasks, such as detection, differentiation from obstacles or other elements in the surroundings. It also requires to obtain the global

or relative position of the object and to define a strategy to be able to adapt to the target's movements.

In previous years, some developments have used the drone camera to detect terrestrial objects, but they did not autonomously follow it or localized it without an external reference (Garzón et al., 2013). Also, (Huang et al., 2010) proposed an approach based on frames differentiation, but it did not perform well enough when facing high frequency vibrations, which are very common when using mini-UAVs. Another development uses LIDAR sensors in order follow objects (Leslar et al., 2011). Yet another approach proved to be able to follow a 3D moving object and keep a distance with it, based on the visual information given by an adaptive tracking method based on the color information (Mondragon et al., 2011). The work presented here differs from previous works because it is able to perform all three sub-tasks in a fully integrated way, it only uses a camera and an ultrasound sensor to perform the following and it uses a GPS to localize the target in global coordinates.

2 Detection

The target detection strategy used in this work is based on comparing a set of characteristics from the objects present on the aerial image against those of the target, which are pre-defined or can be extracted from an initial image. The main characteristics used are color, shape and size.

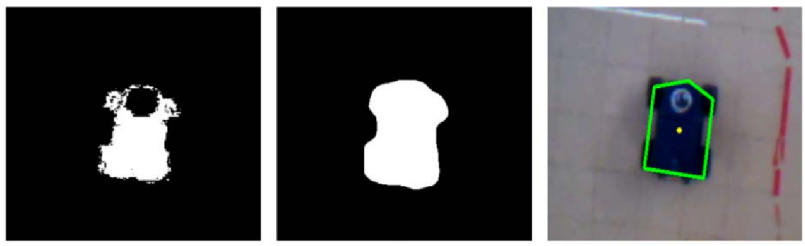
The color is obtained in the HSV color space, to make the system robust against illumination changes. Once it is defined, a binarization method is applied to every pixel of the image. This is done by establishing a threshold in each one of the channels (Hue, saturation and value). The objective of this step is to create a binary image in which every pixel that has the same color as the target will stand out in white over a black background. As mentioned before, the color of the target can be pre-defined or selected in the calibration step.

After this, a post-processing step is applied to the binary image, which includes noise reduction filters, as well as dilation and erosion. The objective of this step is to obtain an image with clearly defined outlines. Moreover, this filtering process can be adapted or fine-tuned according to the scenario where the following will be performed.

After the image is filtered, the shape and size of the objects is analyzed, so as to select only those figures that match the size and form of the target. It is possible to define a correct size of the target in the image plane, because the height at which the UAV is flying is known, and this height pro-

vides a good approximation to the distance from the camera to the object. Also, it should be pointed out that other geometrical characteristics can be included at this point, in case similar objects are found in the surroundings.

Once the target is found in the image, its geometric center is calculated; it represents the position of the target in the image plane, and will be used for the localization process described in Section 3. The final step for the detection process is to highlight the outline of the object in the original image so as to show to the user what is being detected. The overall process is illustrated with Fig. 1.



(a) (b) (c)

Fig. 1. Steps for image treatment: (a) Binarized image, (b) Prepared image, (c) Target highlighted.

3 Localization

The process used to obtain the position of the target in a global coordinate system, is based on an inversion of the Pinhole camera model, which describes the mathematical relationship between the location of a point in the space $(X,Y,Z)^T$ and its projection onto the image plane $(u,v)^T$ of the camera.

The model is shown in Equation (1), where the transformation matrix includes characteristic parameters of the camera. An intrinsic calibration of the camera is needed in order to obtain the parameters of the transformation matrix.

$$\lambda\begin{pmatrix}u\\v\\1\end{pmatrix}=\begin{pmatrix}f & \tau & \sigma_x & 0\\0 & \eta f & \sigma_y & 0\\0 & 0 & 1 & 0\end{pmatrix}\begin{pmatrix}X\\Y\\Z\\1\end{pmatrix} \tag{1}$$

where λ is the scale factor, $(u,v)^T$ the projection of the point onto the image plane expressed in pixels, f the focal distance, τ is the skew parameter which indicated whether the pixels are skew or not, and it will be 0 in case

there is no skew, $(\sigma_x, \sigma_y)^T$ are the coordinates of the center of the image plane, $(X, Y, Z)^T$ are the coordinates of the target in relation to the camera, and η indicates the form of the pixel, if it is 1, then the pixel is a square. The coordinate Z is known because the drone has an ultrasound sensor pointing downwards. It should be as precise as possible to obtain a correct estimation of the position. Therefore, the flight conditions of the drone should be smooth and they should avoid pronounced inclinations, speeds or angular accelerations.

Since the UAV will fly at a height of 8 meters or more, it is possible to assume that the target is flat and ignore its height to the ground. Having this assumption, the matrix model of Equation (1) can be inverted. Moreover, if $(u, v)^T$ is substituted by the coordinates of the centroid of the detected target, it is possible to obtain its position in a reference frame located on the camera optical frame.

The final step of the localization process is to transform this position, from the camera's optical frame to an external, fixed reference frame. This is done by applying a coordinate's transformation to the position of the target. The values of this transformation will be extracted from the localization system of the UAV itself. Moreover, if a GPS is mounted on-board, the position of the target will also be given in global reference frame. Otherwise it will be given in the UAV's odometry frame. Regardless of which external frame is used, the UAV will be able to perform the following step, because this step is based on relative changes of the position of the target.

4 Following algorithm

The objective of this algorithm is to keep the target inside the field of view of the camera, and therefore to extend the tracking as long as possible. A PID controller was selected as the solution for this due to its flexibility, robustness and popularity among industrial environments. And it proved to be capable of controlling the drone effectively.

The position error is defined as the distance in meters between the center of the camera image and the target position, according to the $(x, y)^T$ axis of the coordinate system of the drone.

The regulation actions consist in linear speed commands in each axis. Since the UAV's response for each axis are assumed to be decoupled, two different PID controllers were designed, for x and y axes respectively. Both, the simulated system and the real system were controlled using this method.

In order to adjust the PID controller, the Ziegler-Nichols' closed loop method was used (Quevedo et al., 2000). This selection was made because it is flexible and easy to adjust, and mainly because it does not require a system identification step. This is especially useful if different UAVs are to be used, as is this case.

However, after implementing those PIDs, the result was a slow response of the UAV, and it was not able to perform its task correctly. This behavior is foreseeable since Ziegler-Nichols' methods were designed for industrial plants which have slow dynamics (in contrast to our system, where fast reactions are essential). As a result, these estimations were used as a starting point for the following heuristic adjustment. Moreover, a different adjustment was necessary also for the real drone, and in this case the integral value was minimized because the error in steady state is not a priority, whereas a fast reaction is crucial. The results of the heuristic adjustment are presented in Table 1.

Table 1. Results for PID controller adjustment.

	Ziegler-Nichols'		Simulations		Real world	
	x axis	y axis	x axis	y axis	x axis	y axis
K_p	0.342	0.336	0.35	0.35	0.04	0.04
K_d	0.342	0.388	0.003	0.003	0	0
K_i	0.0427	0.0726	0.025	0.025	0.01	0.01

This PID demonstrated that it could respond to extreme situations such as sudden changes of direction or maximum speed of the Summit XL, keeping the target in every moment inside the framework of action of the ventral camera.

5 Software Architecture

The entire software is supported by the software framework ROS (Robot Operating System). A diagram of the simplified proposed software platform is found in Fig. 2, where the main components are marked by double lines. An external controller was created so as to be able to take off and position the drone at the desired altitude, and takeover control if necessary. Another component is the detection-localization where all the image processing occurs and the last one is the following where the PID controller is implemented.

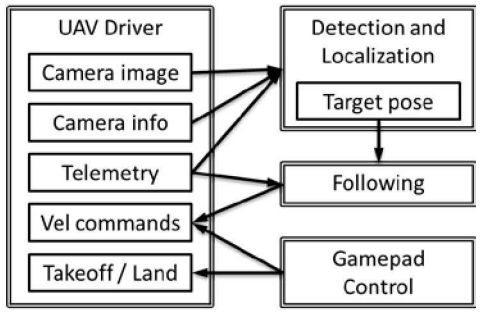


Fig. 2. Simplified nodes and topics of the system.

6 Experiments and results

The experiments are divided in two, simulations and real world tests. For both type of tests, the UGV was tele-operated along the scenario and the UAV perform the autonomous detection, localization and following.

6.1 Simulations

The simulations were done using the Gazebo 3D simulator, using models for the UAV and the UGV. Also, a virtual scenario similar to a critical infrastructure was created for the tests (See Fig. 3).

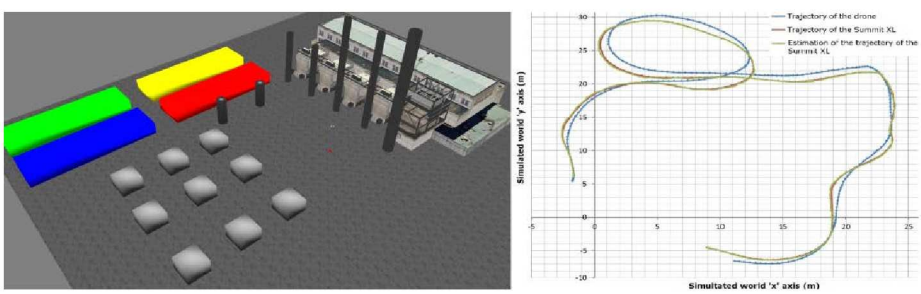


Fig. 3. Simulated world (Left). Example of routes of UGV and UAV (Right).

Several variables were observed along 10 different routes. These routes included big obstacles, red objects (same color as the target), changes of the target's speed (0-3m/s), etc.

6.2 Real world experiments and results

Since the localization of the real UAV is not reliable, the real world tests were done only for the detection and following capabilities. The tests were carried out indoors, with the UAV flying at a height of 6 meters, which can be a handicap because a higher altitude would improve the results by covering a bigger area with the ventral camera. However, the system proved its detection and following capabilities as shown in Fig. 4.

A summary of the results of both simulations and real world experiments is presented in Table 2. It can be seen that a correct detection was achieved in 98.47% of the cases for the simulation and 93.35% for the real world tests. The following task has also a good performance, as shown by the very small mean error obtained (0.18m). It should be pointed out that, in order to avoid errors on the localization, some images are rejected according to the aforementioned flying restrictions, and the reason is that high inclinations of the drone may trigger a bad localization of the target. Those rejections however do not affect the following task.

Fig. 4. Image sequence for real world tests.

Table 2. Results summary.

	Total Images	False negatives	False positives	UGV path length	Mean error
Simulations	10519	1.53%	0%	800m	0.18m
Real world	18.705	6.65%	0.54%	n/a	n/a

7 Conclusions

A system that detects, localizes and follows a mobile ground robot using a mini-UAV is presented. The proposed detection algorithm is simple

enough to be executed on real time and provides a very good detection ratio. The following technique is also robust, and allows following the UGV in long routes always keeping it in the camera's field of view.
The localization of the UGV in a global reference frame was possible only on simulations because of the lack of a good localization with the real robot, however it have proved to be a promising technique for obstacle or mobile objects localization in complex scenarios. The results, both in simulations and with real robots show that the proposed technique can successfully perform its tasks in realistic scenarios and work in real time.

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